

What is claimed is:

1. An apparatus for supporting a manufacturing tool relative to a workpiece, the apparatus comprising:

5 a track assembly adapted to be attached to the workpiece and including at least one rail, the rail having a longitudinally-extending neutral axis and a rack extending along a pitch line that at least approximately coincides with the longitudinally-extending neutral axis.

2. The apparatus of Claim 1, wherein the rack is integrally-formed in the rail.

10 3. The apparatus of Claim 1, wherein the rack comprises a plurality of apertures.

4. The apparatus of Claim 1, wherein the rack comprises a plurality of apertures, at least some of the apertures being tapered, wedge-shaped apertures.

15 5. The apparatus of Claim 1, wherein the rack comprises a plurality of apertures, at least some of the apertures being tapered, conically-shaped apertures.

20 6. The apparatus of Claim 1, wherein the rail comprises a substantially flat member having a width substantially greater than a thickness of the substantially flat member, the substantially flat member being substantially stiffer in bending about a stiff axis that extends in a first direction aligned along the thickness of the substantially flat member, and being substantially more flexible in bending about a bending axis that extends in a second direction aligned along the width of the substantially flat member.

25 7. The apparatus of Claim 1, wherein the rail comprises a first rail and wherein the track assembly includes a second rail oriented approximately parallel to the first rail, the first and second rails each having a longitudinally-extending neutral axis and a rack, the rack extending along a pitch line that at least approximately coincides with the longitudinally-extending neutral axis.

30 8. The apparatus of Claim 1, wherein the track assembly includes:

first and second elongate flexible rails, the rails being spaced apart and approximately parallel to each other; and

35 a plurality of vacuum attachment devices connected to each rail and spaced at intervals therealong for releasably attaching each rail to the surface of the workpiece by



vacuum, with the widths of the rails extending substantially parallel to the surface of the workpiece, the rails bending and twisting as needed to substantially follow the surface of the workpiece.

5        9.        The apparatus of Claim 8, wherein each rail is relatively stiff in bending about a first bending axis and relatively flexible in bending about a second bending axis orthogonal to the first bending axis, and wherein each rail is mounted on the workpiece such that the first bending axis is substantially normal to the workpiece surface and the second bending axis is substantially parallel to the workpiece surface.

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10.       The apparatus of Claim 1, further comprising a carriage moveably coupled to the track assembly and moveable relative to the workpiece along the at least one rail, the carriage including a tool support adapted to receive and support a manufacturing tool.

15       11.       The apparatus of Claim 10, wherein the carriage includes a drive assembly adapted to drive the carriage along the track assembly and having a drive motor coupled to a drive gear, the drive gear operatively engaging the rack.

20       12.       The apparatus of Claim 10, wherein the rack includes a plurality of apertures and wherein the carriage includes a drive assembly adapted to drive the carriage along the track assembly and having a drive motor coupled to a drive gear, the drive gear having a plurality of teeth, at least some of the teeth operatively engaging the apertures of the rack, the apertures being adapted to match a cross-sectional profile of the teeth.

25       13.       The apparatus of Claim 10, further comprising an opposing-force support assembly operatively coupled to the carriage and adapted to be secured to the workpiece to at least partially counterbalance a manufacturing force exerted on the workpiece by the manufacturing tool.

30       14.       The apparatus of Claim 10, wherein the carriage includes an x-axis portion moveably coupled to the track assembly, and a y-axis portion moveably coupled to the x-axis portion and moveable with respect to the x-axis portion along a y-axis oriented transversely to the track assembly.

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15. An assembly for performing a manufacturing operation on a workpiece, the assembly comprising:

a track assembly adapted to be attached to the workpiece and including at least one rail, the rail having a longitudinally-extending neutral axis and a rack extending along a pitch line that at least approximately coincides with the longitudinally-extending neutral axis;

a carriage moveably coupled to the track assembly and moveable relative to the workpiece along the track assembly, the carriage including a tool support adapted to receive and support a manufacturing tool; and

a manufacturing tool coupled to the tool support and adapted to be engageable with the workpiece to perform the manufacturing operation on the workpiece.

16. The assembly of Claim 15, wherein the rack is integrally-formed in the rail.

17. The assembly of Claim 15, wherein the rack comprises a plurality of apertures.

18. The assembly of Claim 15, wherein the rack comprises a plurality of apertures, at least some of the apertures being tapered, wedge-shaped apertures.

19. The assembly of Claim 15, wherein the rack comprises a plurality of apertures, at least some of the apertures being tapered, conically-shaped apertures.

20. The assembly of Claim 15, wherein the rail comprises a substantially flat member having a width substantially greater than a thickness of the substantially flat member, the substantially flat member being substantially stiffer in bending about a stiff axis that extends in a first direction aligned along the thickness of the substantially flat member, and being substantially more flexible in bending about a bending axis that extends in a second direction aligned along the width of the substantially flat member.

21. The assembly of Claim 15, wherein the rail comprises a first rail and wherein the track assembly includes a second rail oriented approximately parallel to the first rail, the first and second rails each having a longitudinally-extending neutral axis and a rack, the rack extending along a pitch line that at least approximately coincides with the longitudinally-extending neutral axis.



22. The assembly of Claim 15, wherein the track assembly includes:

first and second elongate flexible rails, the rails being spaced apart and approximately parallel to each other; and

a plurality of vacuum attachment devices connected to each rail and spaced at intervals therealong for releasably attaching each rail to the surface of the workpiece by vacuum, with the widths of the rails extending substantially parallel to the surface of the workpiece, the rails bending and twisting as needed to substantially follow the surface of the workpiece.

23. The assembly of Claim 22, wherein each rail is relatively stiff in bending about a first bending axis and relatively flexible in bending about a second bending axis orthogonal to the first bending axis, and wherein each rail is mounted on the workpiece such that the first bending axis is substantially normal to the workpiece surface and the second bending axis is substantially parallel to the workpiece surface.

24. The assembly of Claim 15, wherein the carriage includes a drive assembly adapted to drive the carriage along the track assembly and having a drive motor coupled to a drive gear, the drive gear operatively engaging the rack.

25. The assembly of Claim 15, wherein the rack includes a plurality of apertures and wherein the carriage includes a drive assembly adapted to drive the carriage along the track assembly and having a drive motor coupled to a drive gear, the drive gear having a plurality of teeth, at least some of the teeth operatively engaging the apertures of the rack, the apertures being adapted to match a cross-sectional profile of the teeth.

26. The assembly of Claim 15, further comprising an opposing-force support assembly operatively coupled to the carriage and adapted to be secured to the workpiece to at least partially counterbalance a manufacturing force exerted on the workpiece by the manufacturing tool.

27. The assembly of Claim 15, wherein the carriage includes an x-axis portion moveably coupled to the track assembly, and a y-axis portion moveably coupled to the x-axis portion and moveable with respect to the x-axis portion along a y-axis oriented transversely to the track assembly.



28. The assembly of Claim 15, wherein the manufacturing tool includes a drill and the manufacturing operation includes a drilling operation.

29. A method of performing a manufacturing operation on a workpiece, the method comprising:

5 attaching a track assembly to the workpiece, the track assembly including at least one rail having a longitudinally-extending neutral axis and a rack extending along a pitch line that at least approximately coincides with the longitudinally-extending neutral axis;

moveably supporting a manufacturing tool on the track assembly;

engaging a drive apparatus with the rack; and

10 driving the manufacturing tool along the track assembly using the drive apparatus.

30. The method of Claim 29, wherein attaching a track assembly to the workpiece includes applying a suction force against the workpiece with the track assembly.

15 31. The method of Claim 29, wherein attaching a track assembly to the workpiece includes attaching a track assembly having at least one rail that includes a rack integrally-formed in the rail.

20 32. The method of Claim 29, wherein attaching a track assembly to the workpiece includes attaching a track assembly having at least one rail that includes a rack comprising a plurality of apertures.

25 33. The method of Claim 29, wherein attaching a track assembly to the workpiece includes attaching a track assembly having at least one rail that includes a rack comprising a plurality of apertures, at least some of the apertures being tapered, wedge-shaped apertures.

30 34. The method of Claim 29, wherein attaching a track assembly to the workpiece includes attaching a track assembly having at least one rail that includes a rack comprising a plurality of apertures, at least some of the apertures being tapered, conically-shaped apertures.

35. The method of Claim 29, wherein attaching a track assembly to the workpiece includes attaching a track assembly having at least one rail, wherein the rail comprises a substantially flat member having a width substantially greater than a thickness of the



substantially flat member, the substantially flat member being substantially stiffer in bending about a stiff axis that extends in a first direction aligned along the thickness of the substantially flat member, and being substantially more flexible in bending about a bending axis that extends in a second direction aligned along the width of the substantially flat member.

36. The method of Claim 29, wherein moveably supporting a manufacturing tool on the track assembly includes moveably coupling a carriage to the track assembly, the carriage including a tool support adapted to receive and support a manufacturing tool.

37. The method of Claim 29, wherein moveably supporting a manufacturing tool on the track assembly includes moveably coupling a carriage to the track assembly, the carriage including a drive assembly adapted to drive the carriage along the track assembly and having a drive motor coupled to a drive gear, the drive gear operatively engaging the rack.

38. The method of Claim 29, wherein engaging a drive apparatus with the rack includes engaging at least one tooth with at least one aperture, the aperture being adapted to match a cross-sectional profile of the tooth.

39. The method of Claim 29, further comprising performing a manufacturing operation on the workpiece using the manufacturing tool.

40. The method of Claim 39, wherein performing a manufacturing operation includes performing a drilling operation.

41. The method of Claim 29, further comprising applying an opposing force against the workpiece using an opposing-force support assembly, the opposing force being in a direction substantially opposing a manufacturing force exerted against the workpiece during a manufacturing operation.

42. The method of Claim 41, further comprising simultaneously with applying an opposing force, performing a manufacturing operation on the workpiece using the manufacturing tool.

